

SUSTAINABLE SPOT TREATMENT FOR SRI LANKA'S HIGHWAY CURVES

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Abstract

Sri Lanka records nearly 38,000 road crashes annually, causing over 3,000 deaths and 8,000 serious injuries, with losses equal to 3 to 5 percent of national gross domestic product (GDP). Roughly 45 percent of fatal and grievous crashes occur where excessive speed meets hazardous horizontal curves in the central highlands, yet existing safety measures rely mainly on driver-behaviour campaigns and civil works rather than pavement friction restoration. This study examines whether locally sourced aggregate can support High Friction Surface Treatment (HFST) as an affordable, low-carbon spot treatment for such curves, reducing dependence on imported bauxite and proprietary resins. Local quarry samples were tested against UK and AASHTO aggregate specifications, and three resurfacing options, hot-mix asphalt overlay, double bituminous surface treatment, and polymer-resin HFST, were compared using a ten-year Life-Cycle Assessment and Life-Cycle Cost Analysis. Quarry sources from Kandy and Anuradhapura met required friction and durability thresholds. HFST produced the lowest ten-year carbon footprint, despite a higher initial cost, and offered wet-weather crash reduction of 60–83% versus 15–25% for conventional treatment, with service life exceeding ten years. These results empirically indicate that domestically manufactured HFST, applied selectively at high-risk curves, offers a durable, economical, environmentally favourable safety solution for Sri Lanka's mountainous highway network, further warranting pilot-scale field trials on system-level performance.

Keywords: Highway crashes, Pavement friction, High friction surface treatment, Horizontal curves, Life-cycle assessment

1. Introduction

Road traffic collisions remain one of Sri Lanka's most persistent public-safety and economic burdens. The country records approximately 38,000 crashes each year, resulting in more than 3,000 deaths and 8,000 serious injuries, with direct and indirect losses estimated at 3–5% of national Gross Domestic Product (GDP) [1]. A substantial share of this toll originates in the hill country, where narrow, winding alignments force drivers to negotiate tight horizontal curves. Excessive approach speed combined with unfavourable curve geometry is implicated in nearly 45% of fatal and grievous crashes nationwide [2].

National road-safety programmes have historically emphasised driver-behaviour campaigns and conventional civil works: widening the carriageway, improving sight distance, or installing speed-calming humps. Yet, international pavement-engineering evidence points to a more direct lever: restoring skid resistance at the tyre–pavement interface. High Friction Surface Treatment (HFST), in which a thin epoxy or polyester-resin binder locks a highly angular, polish-resistant aggregate onto the wearing course, has been shown to cut curve-related crashes by 50–100% in mature road networks abroad, while lasting 7–15 years and returning a favourable benefit-cost ratio [3,4].

The barrier to adopting HFST locally is not its performance but its supply chain: specification-grade aggregates such as calcined bauxite, and the proprietary resins paired with them, are almost entirely imported, which inflates first cost and undermines sustainability. This study therefore investigates whether aggregate sourced from domestic quarries can substitute for imported material in a curve-specific (point-of-curvature to point-of-tangent) spot treatment, offering upcountry Sri Lanka a safety intervention that is simultaneously affordable, durable, and low-carbon.

2. Research Objectives and Methodology

The study set out to characterise candidate Sri Lankan quarry aggregates against internationally recognised HFST specifications, and benchmark a locally sourced HFST against two conventional resurfacing treatments: a Hot-Mix Asphalt (HMA) overlay and a Double Bituminous Surface Treatment (DBST), through a combined Life-Cycle Assessment (LCA) and Life-Cycle Cost Analysis (LCCA), so that the environmental and financial trade-offs of each option could be compared on equal terms.

Rock samples were collected from quarries in the Colombo, Kurunegala, Kalutara, Anuradhapura and Kandy districts and tested for Polished Stone Value (PSV), Sodium-Sulphate Soundness (SSS), Los Angeles Abrasion Resistance (LAAB), and moisture content, following the United Kingdom (UK) Design Manual for Roads and Bridges and the AASHTO HFST aggregate criteria [3]. In parallel, a cradle-to-gate-plus-use-phase LCA was built in accordance with ISO 14040/14044 for a 1 m² functional unit over a 10-year analysis period, comparing a 40-mm HMA overlay (96.0 kg/m² aggregate, 4.8 kg/m² binder), a two-cycle DBST/emulsion treatment (40.0 kg/m² aggregate, 4.0 kg/m² emulsion, 5-year cycle life), and a polymer-resin HFST using the local aggregate (8.0 kg/m² aggregate, 1.45 kg/m² epoxy resin, 10-year life) [4]. A parallel 10-year present-value LCCA, discounted at a 4% real rate, captured initial construction cost together with scheduled maintenance for each option.

3. Results and Analysis

Anuradhapura and Kandy quarry sources met the target specification for low-to-medium-volume rural highways. Anuradhapura aggregate returned a Polished Stone Value of 62, soundness loss of 1.8%, Los Angeles abrasion of 35%, and moisture content of 0.42%; Kandy aggregate returned corresponding values of 61, 1.9%, 30%, and 0.42%. These results satisfy the UK G1/S2 category thresholds for curves of radius below 500 m carrying up to 1,000 commercial vehicles per lane per day, confirming that domestic rock can technically replace imported calcined bauxite for this application [3,4].

The LCA results were, at first glance, counter-intuitive: although the epoxy resin used in HFST carries a far higher embodied-carbon factor (3.80 kg CO₂e/kg) than paving-grade bitumen (0.48 kg CO₂e/kg), the treatment's thin cross-section keeps total material use down to roughly 9.5 kg/m² versus over 100 kg/m² for an HMA overlay. HFST also avoids the plant-heating emissions inherent to hot-mix production. Across the 10-year horizon this yields a global warming potential of 5.85 kg CO₂e/m² for HFST, against 28.0 kg CO₂e/m² for DBST and 19.7 kg CO₂e/m² for HMA, a 39% reduction relative to the conventional overlay.

Table 1: Comparative material, environmental, and economic performance of the three resurfacing options over a 10-year horizon.

Parameter	HMA Overlay	DBST Emulsion	Polymer HFST
Friction service life (years)	4–6	2–4	>10
Re-treatment cycles, 10 yr	2	4	1
Material mass (kg/m ²)	100.8	44.0	9.45
Embodied carbon (kg CO ₂ e/m ²): a	19.7	28.0	5.85
Initial cost (US\$/m ²)	22.00	6.50	32.00
10-yr NPV, 4% discount (US\$/m ²)	40.08	19.10	32.00
Wet-weather crash reduction, assumed	20% (15–25%)	10% (5–25%)	50% (60–83%)
Benefit-cost ratio (BCR): b	0.56	0.58	1.74

a: Aggregate is assumed sourced from the Kandy quarry (≈ 35 km haul) and bitumen/emulsion/resin from Colombo (≈ 150 km).

b: Representative curve above; 6 crashes/yr (Sri Lankan black-spot threshold), 35% wet-weather share (rainfall-exposure proxy), and national casualty costs of US\$70,000/fatality (derived from published Sri Lankan human-capital estimates), US\$10,500/serious and US\$1,400/minor injury. Benefit-cost ratio (BCR) obtained by monetising the crash reduction attributable to each option at a representative highland curve (A5 Kandy–Nuwara Eliya corridor, radius <500 m; treated area 2,800 m², comprising a 150 m approach and 250 m curve body).

On a like-for-like initial-cost basis, HFST is the most expensive of the three. However, this comparison understates its practical case, because HFST is not proposed as a continuous-corridor resurfacing but as a spot treatment confined to the highest-risk curve approach and body. Applied only where crash risk is concentrated, its cost is incurred over a small treated area rather than the full carriageway length, while its friction service life exceeds ten years against four to six for HMA and two to four per DBST cycle, avoiding at least one, and possibly two, repeat interventions that a conventional treatment would require within the same period. Its reported wet-weather crash-reduction potential of 60–83%, roughly three to four times that of the alternatives, further strengthens the safety return per dollar spent when the treatment is targeted rather than applied uniformly [3,4].

Taken together, the material-testing and LCA/LCCA results indicate that on an empirical level, Anuradhapura- and Kandy-sourced aggregate can support a domestically manufactured HFST that is both lower-carbon and, when confined to genuinely high-risk curves, economically competitive with conventional resurfacing. Substituting local rock for imported calcined bauxite additionally removes the freight-related emissions and price volatility associated with overseas sourcing, positioning curve-specific HFST as a practical, sustainable safety intervention for Sri Lanka's central highland road network.

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INTRODUCTION & PROBLEM

- ❖ Road Crash Statistics (Sri Lanka): ~38,000 crashes per year, resulting in over 3,000 fatalities and 8,000 serious injuries, causing an economic loss equal to 3–5% of national GDP.
- ❖ High-Risk Road Segments: Winding mountain alignments in the central highlands account for nearly 45% of fatal and grievous crashes due to excessive speed on hazardous horizontal curves.
- ❖ Supply Chain Bottleneck: High Friction Surface Treatment (HFST) adoption is hindered by the high cost of importing calcined bauxite and proprietary resins.

Proposed Solution:
Domestic aggregates
to develop an
affordable, low-
carbon HFST spot
treatment

METHODOLOGY & LIFE-CYCLE ASSESSMENT

- ❖ Aggregate Characterization: Geological samples from quarries were tested for PSV, LAHV, Soundness, and Moisture Content under UK and AASHTO HFST specifications.
- ❖ 10-Year Life-Cycle Modelling: A cradle-to-gate plus use-phase ISO 14040/14044 LCA and LCCA were conducted over a 1 m² functional unit across a 10-year service life.
- ❖ Evaluated Alternatives: 40-mm HMA overlay vs. DBST-2 cycles vs. Polymer-Resin HFST using local aggregate.
- ❖ Targeted Deployment Model: Spot treatment confined to high-friction demand zones rather than continuous corridor paving

RESULTS & KEY FINDINGS

- ❖ Local Aggregate Compliance: Anuradhapura (PSV 62, LAHV 35%) and Kandy (PSV 61, LAHV 30%) aggregates met UK G1/S2 specification thresholds, confirming local stone can replace imported calcined bauxite.
- ❖ 10-Year Carbon Footprint (GWP): HMA = 9.61 kgCO₂e/m²; DBST = 6.99 kgCO₂e/m²; HFST = 5.85 kgCO₂e/m² (achieving a 39% footprint reduction compared to HMA).
- ❖ Material Efficiency: HFST requires only 9.45 kg/m² total material mass compared to 100.8 kg/m² for an HMA overlay.
- ❖ Safety & Durability: Local HFST provides a friction service life exceeding 10 years and a wet-weather crash reduction potential of 60–83%